

Color

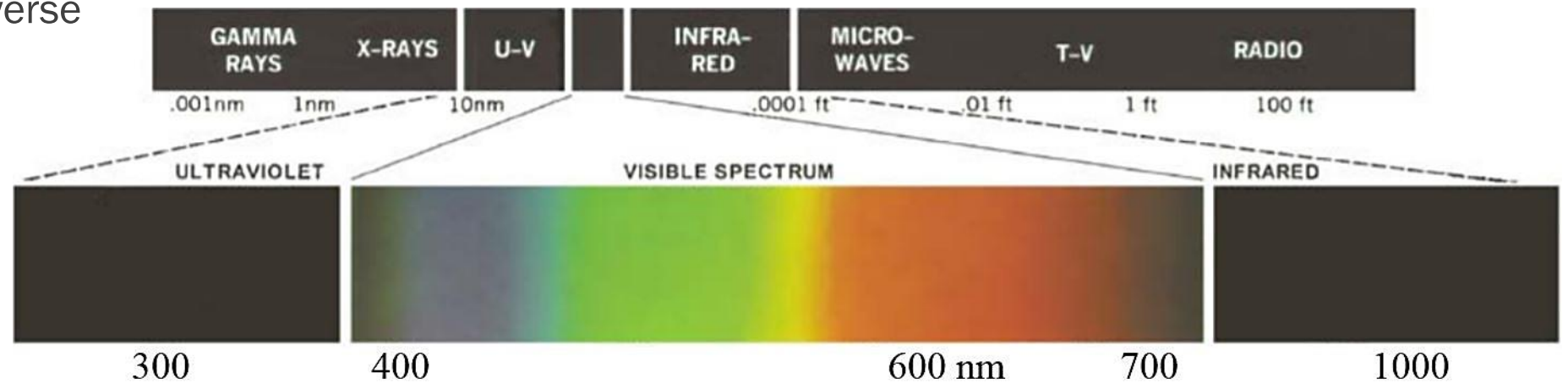
Dr. Tushar Sandhan

Introduction

- Color of the Universe

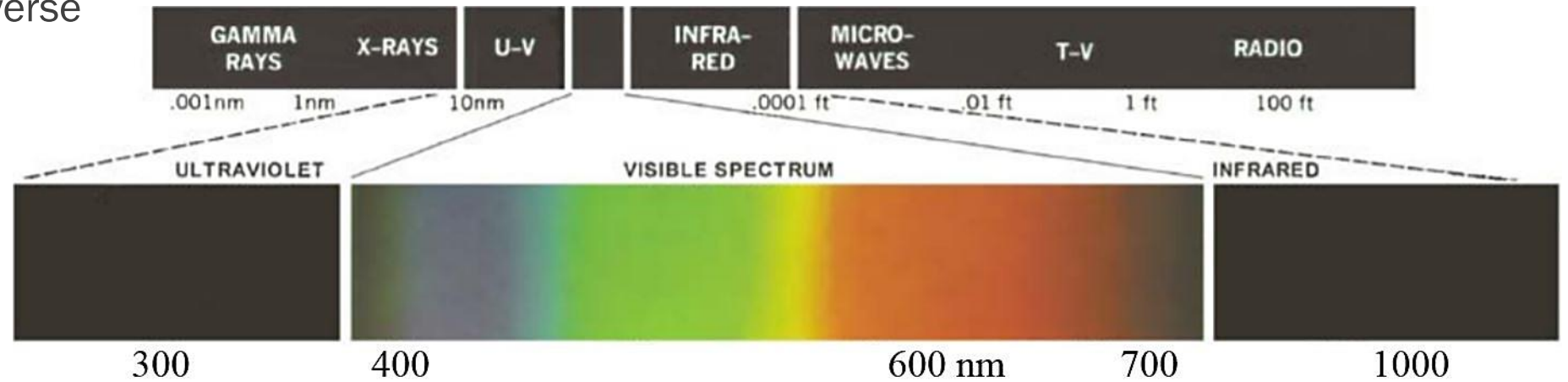
Introduction

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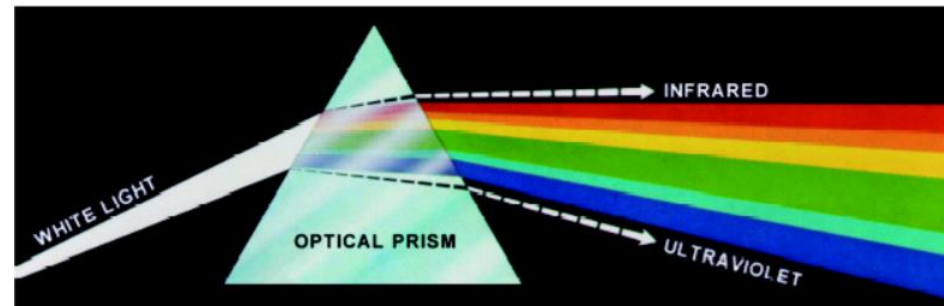


Introduction

- Color of the Universe

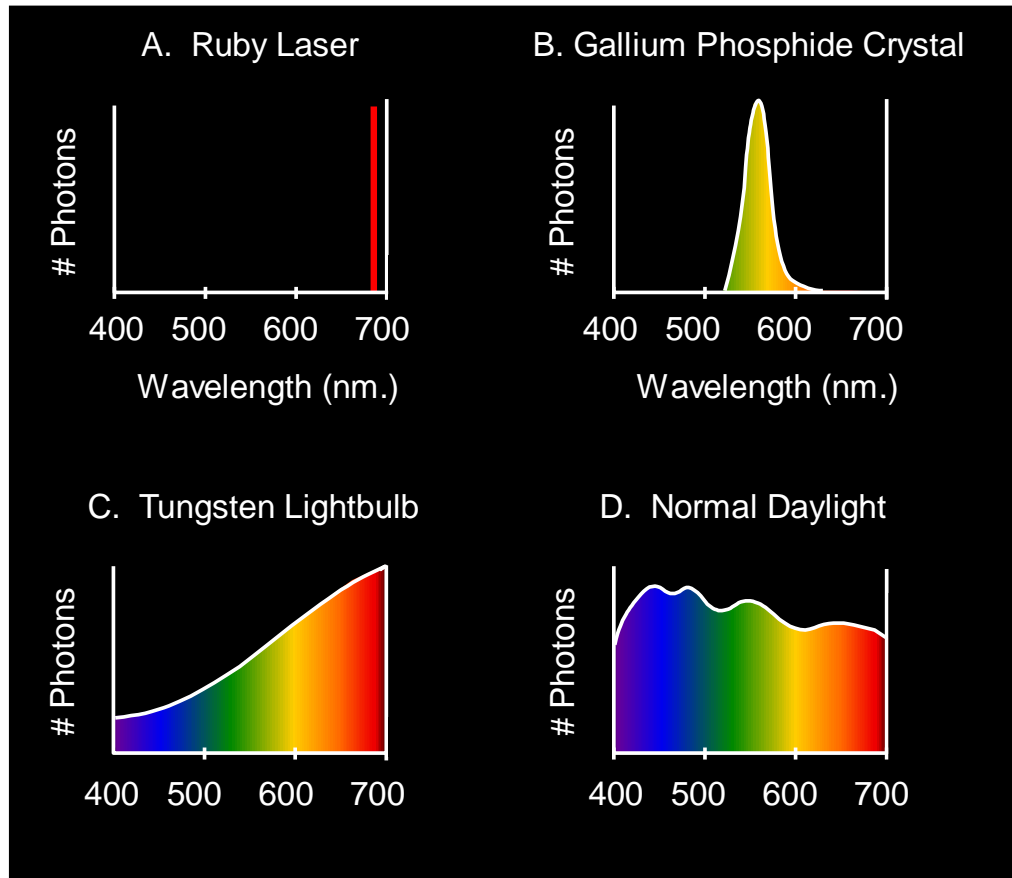


- Visible light (dispersion)



Spectra of objects

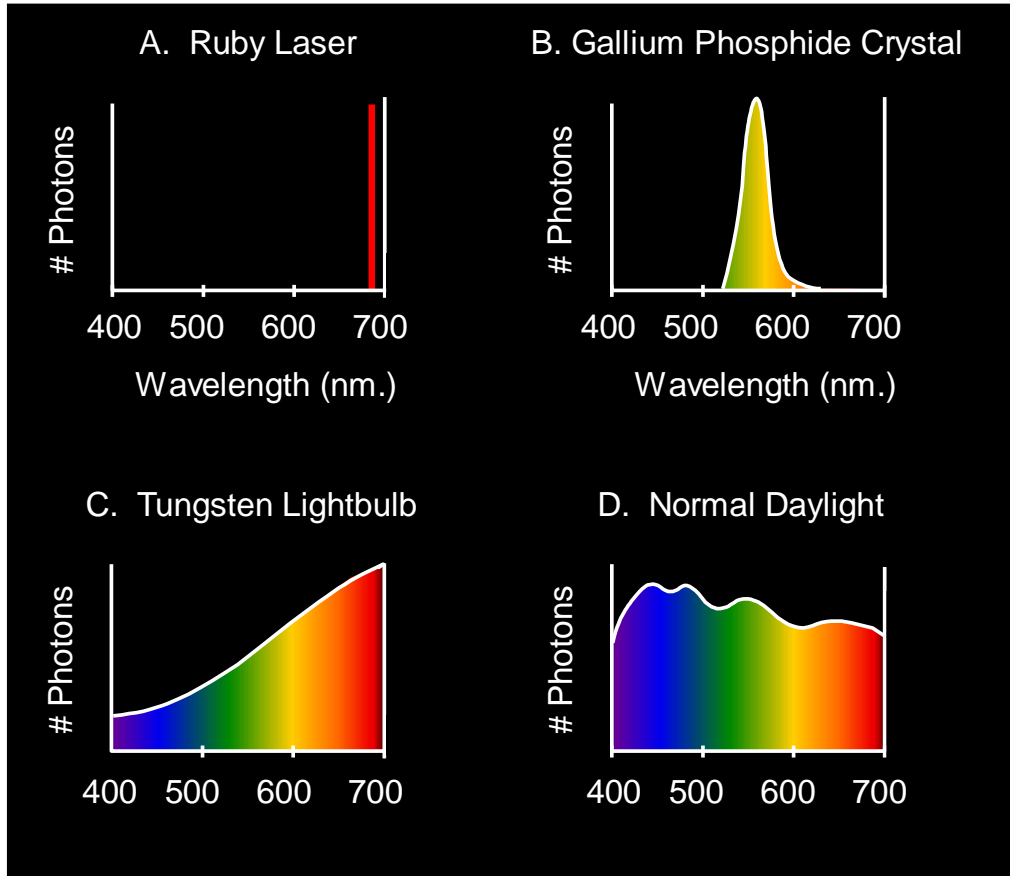
Light source spectra



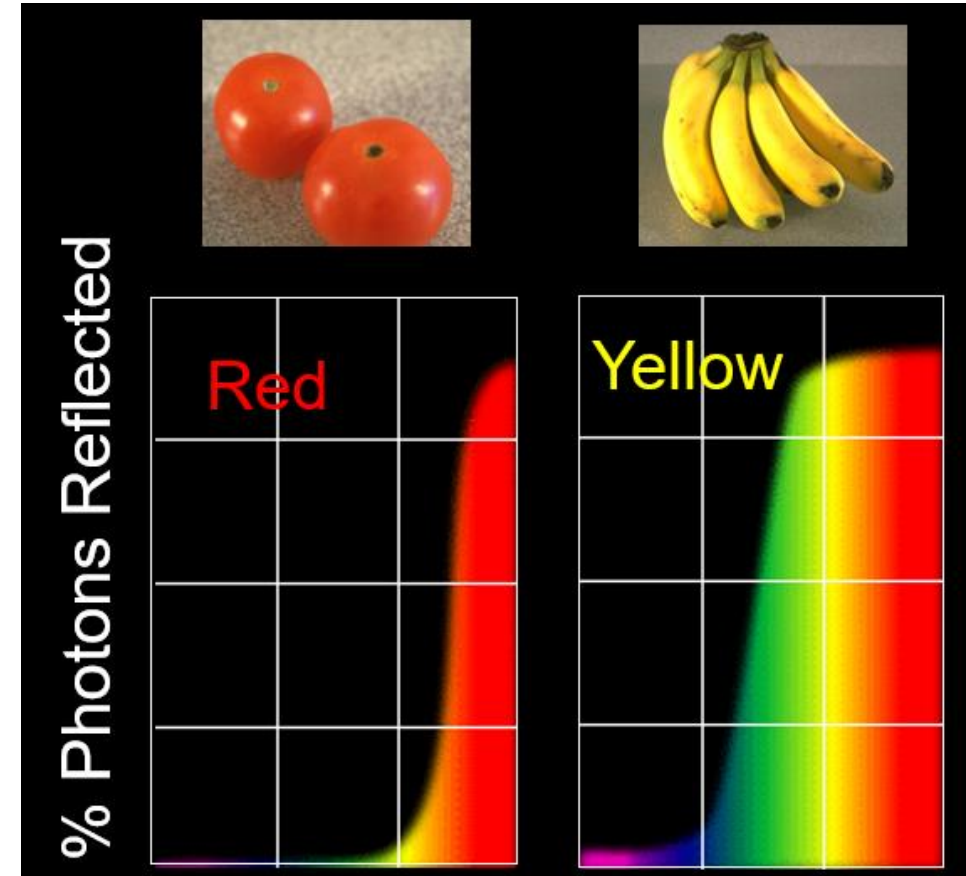
credit: E. Palmer

Spectra of objects

Light source spectra



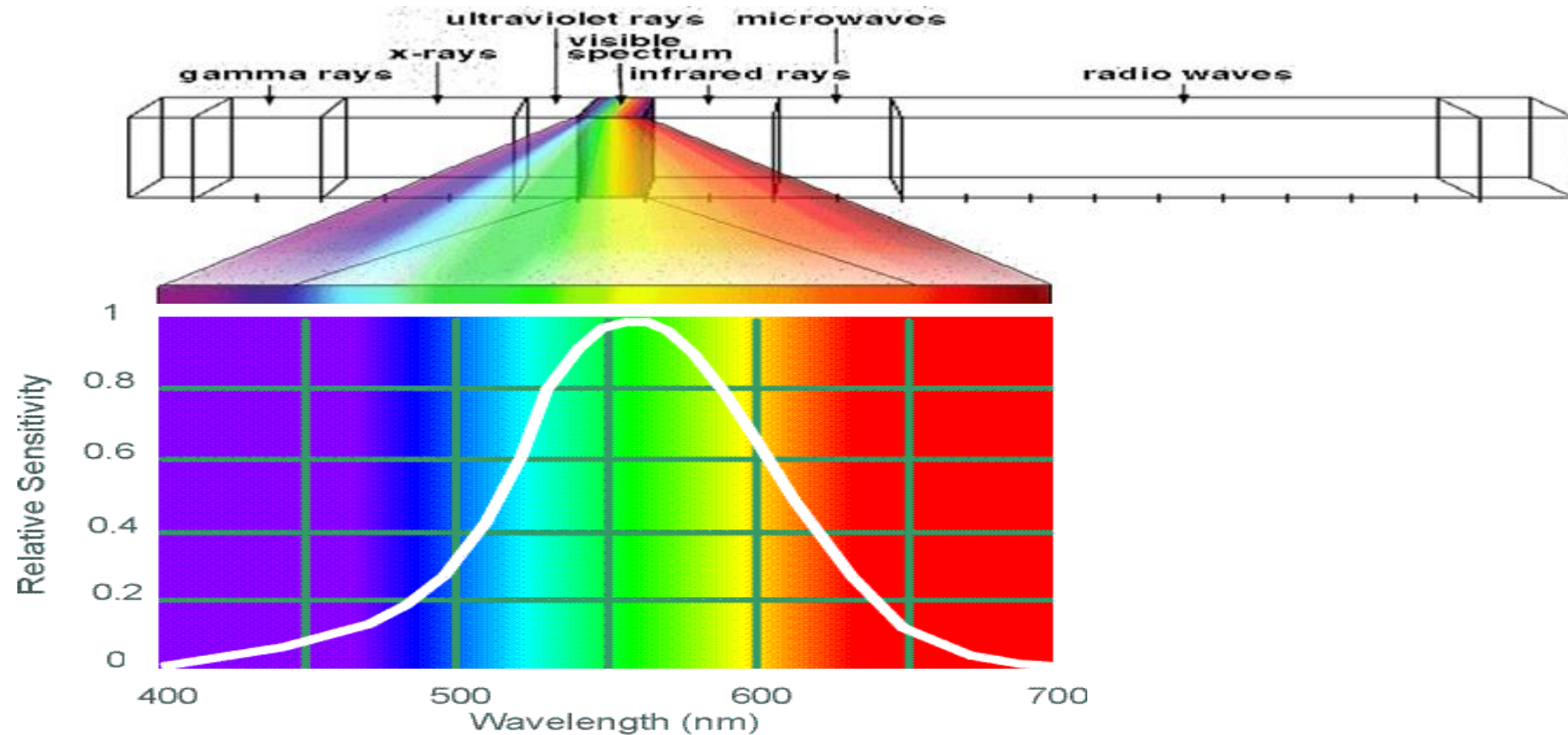
Reflectance spectra of surfaces



credit: E. Palmer

Color

- Human Luminance sensitivity



credit: Efros

Color

- Light spectrum is continuous,
then why are images RGB?

Color

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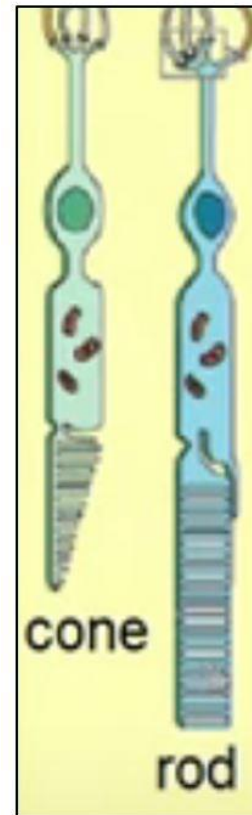


Color

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then why are images RGB?
- ▲ Evolutionary cones (6 million)

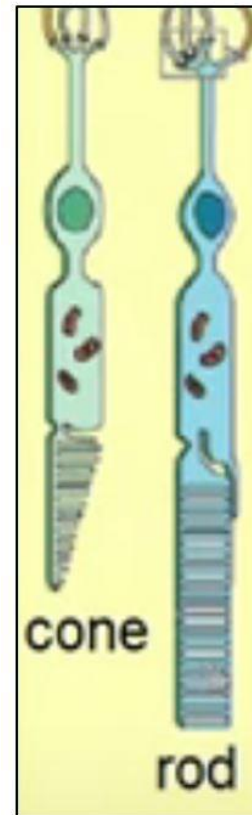
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Color

- Light spectrum is continuous, then why are images RGB?
- ▲ Evolutionary cones (6 million)
- Characterization of cone cells & understanding visual process in the eye.
 - Ragnar Granit, Haldan Keffer Hartline and George Wald
 - Nobel Prize 1967

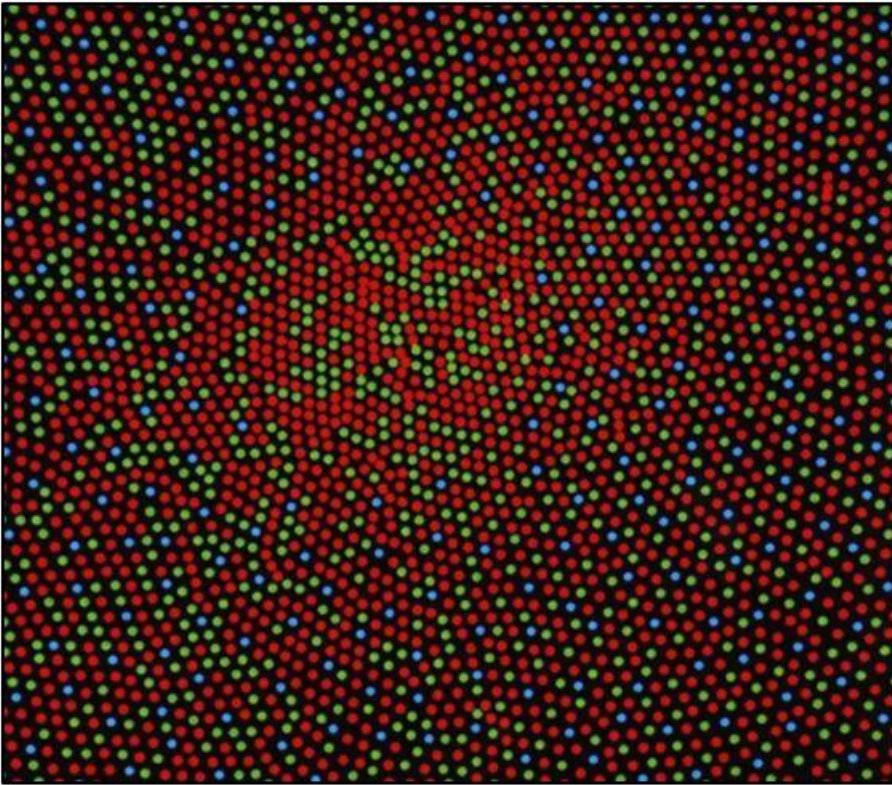


Color

- HVS retina display

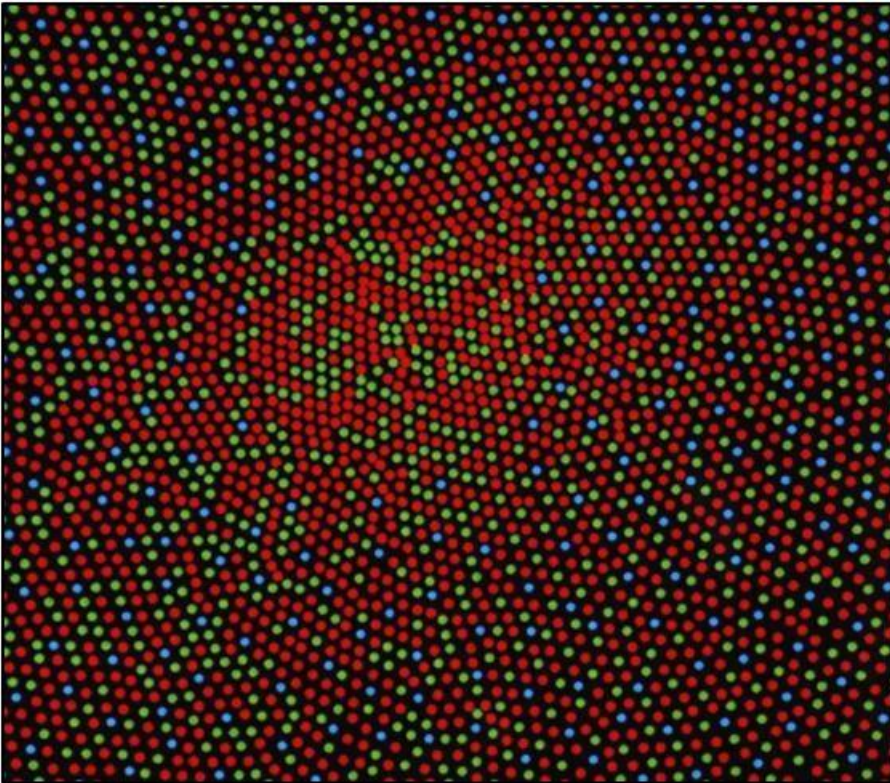
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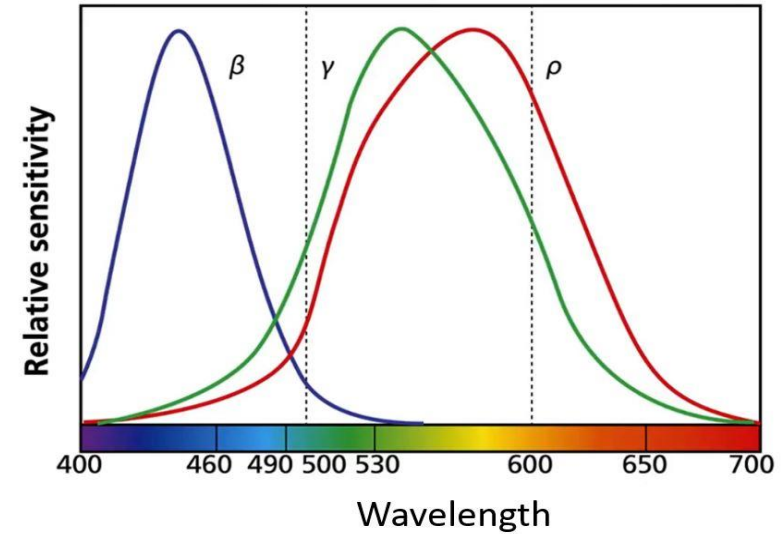


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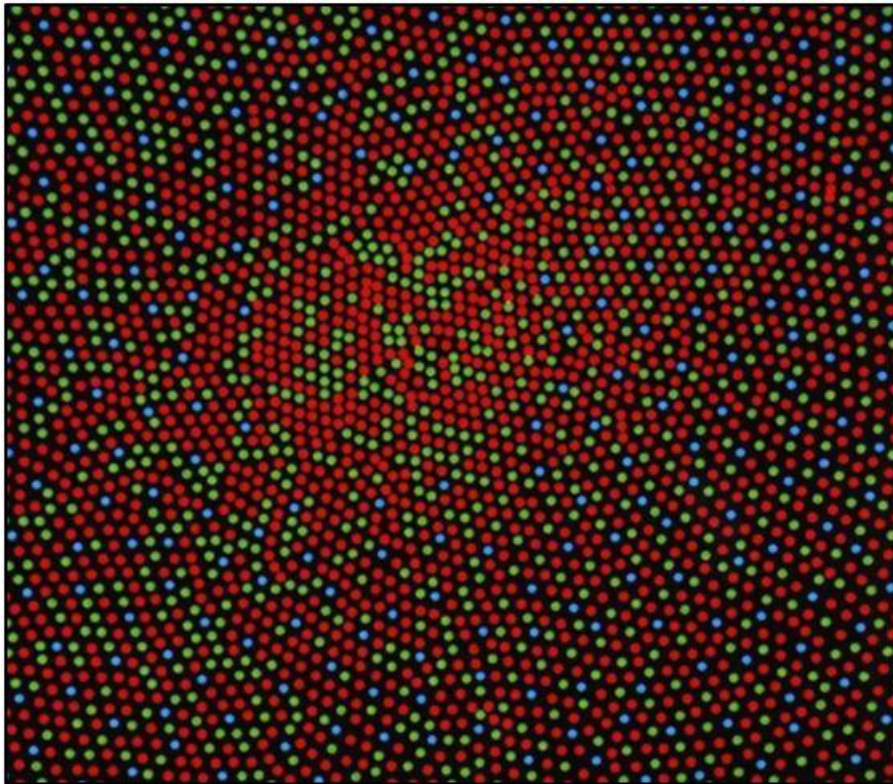


Three cone types (ρ , γ , β) correspond roughly to R, G, B.

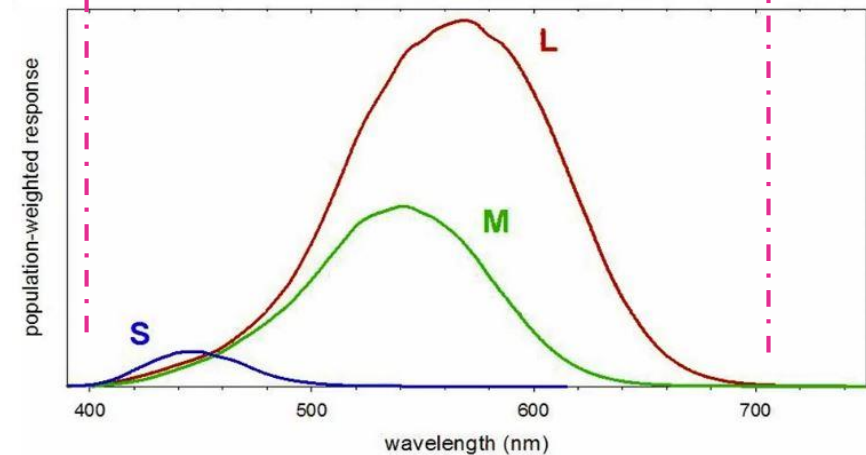
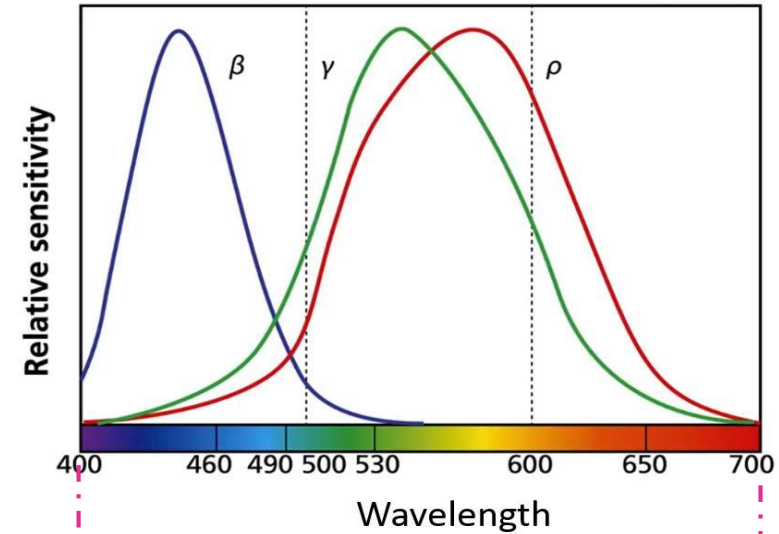


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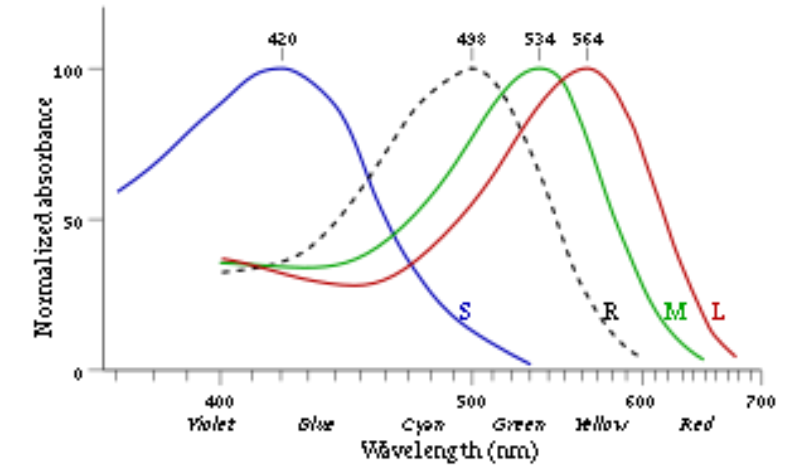


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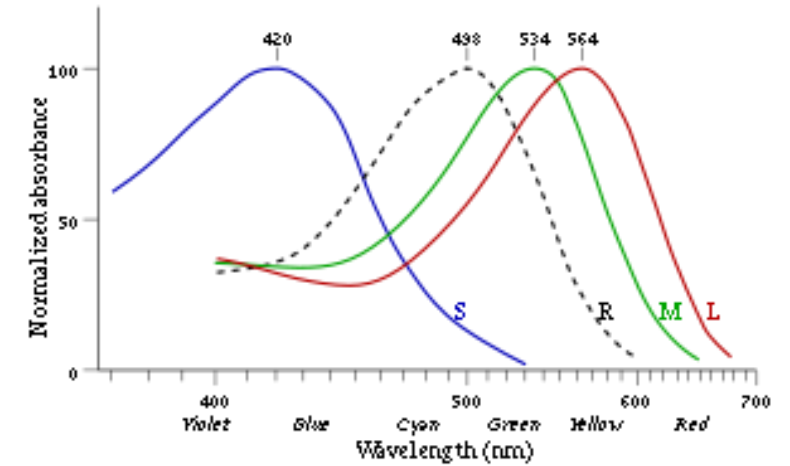
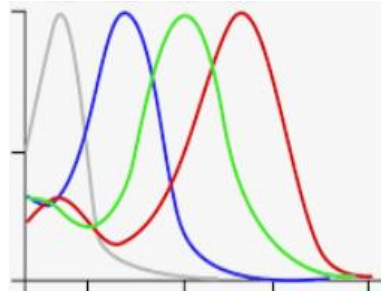
Color

- Cones (Long:L, Medium:M, Short:S) & Rods:R
- S: blue (most sensitive)
- M, L on chromosome X (some women are tetrachromatic)



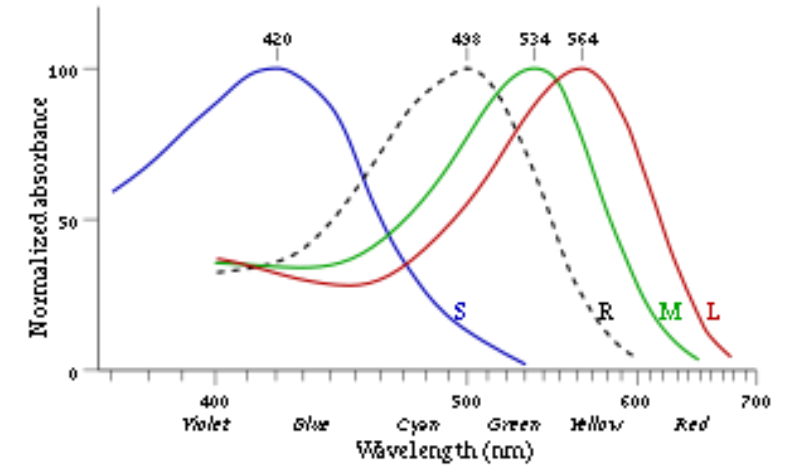
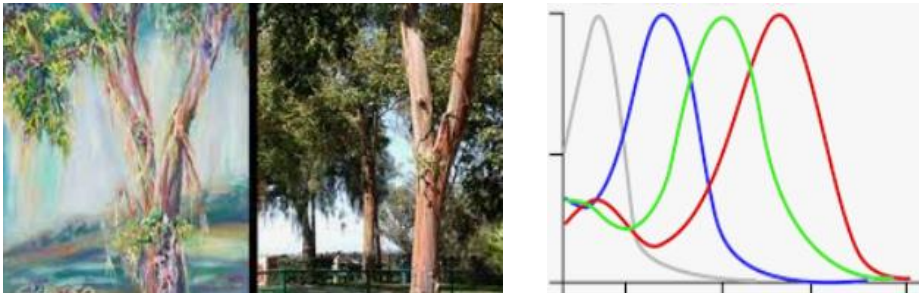
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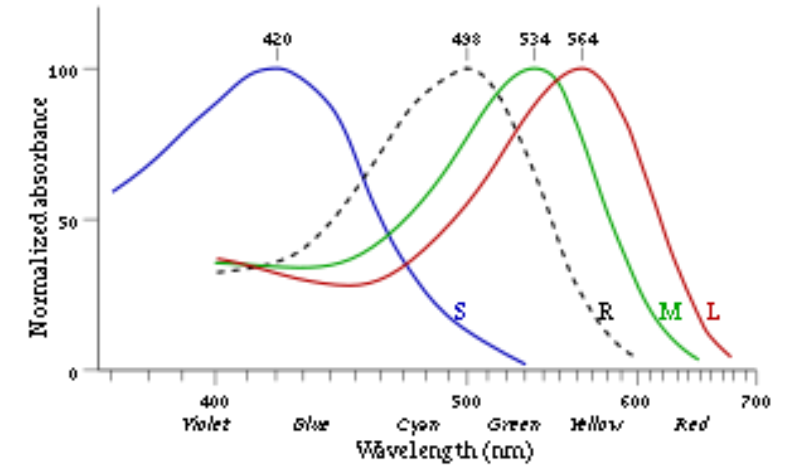
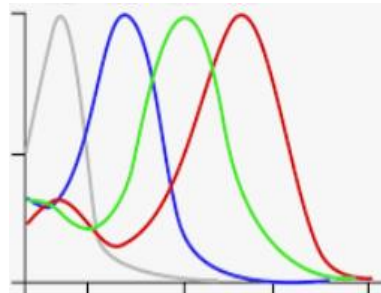
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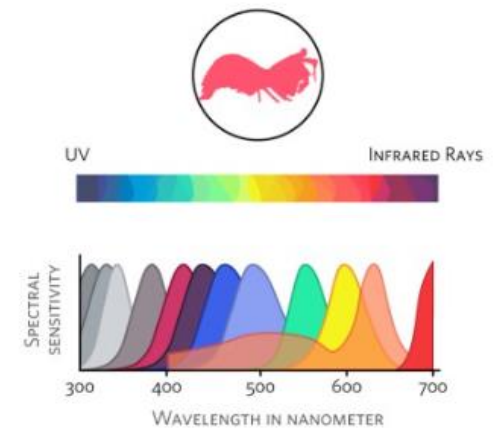
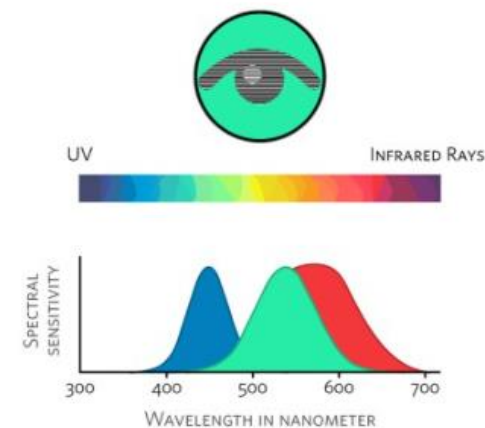
- Reptiles : 5 types of cones
- Mantis shrimp: 12 types of cones

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 - ▶ psychophysical: physiological sequence of sensory processing
 - ▶ perceptual: cognitive representation of a physical reality

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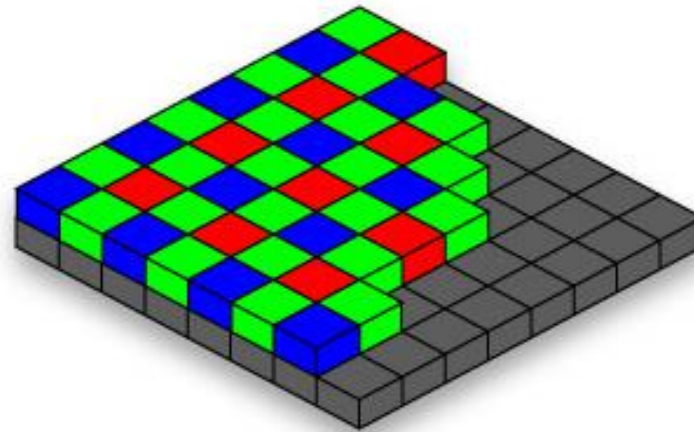
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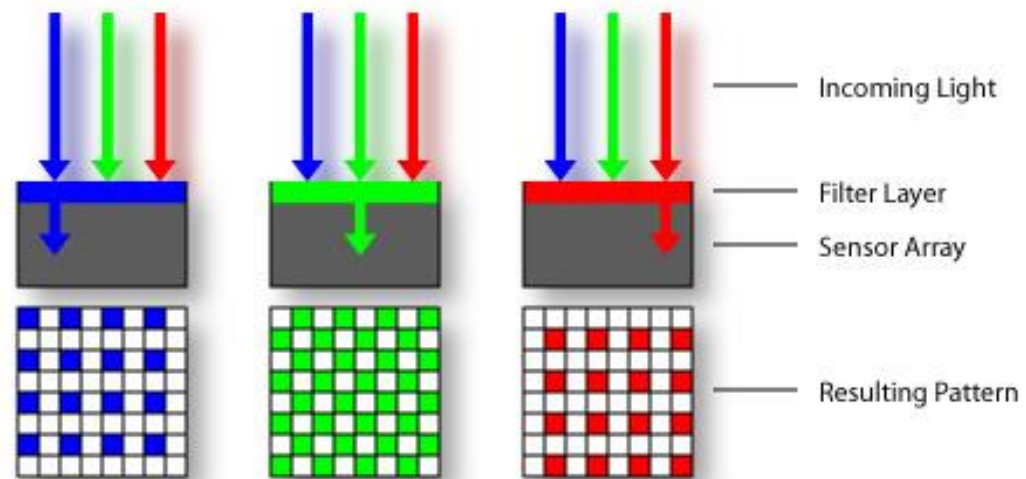
- Imagination of the illuminated retina!

Color

- Sensing



Bayer pattern

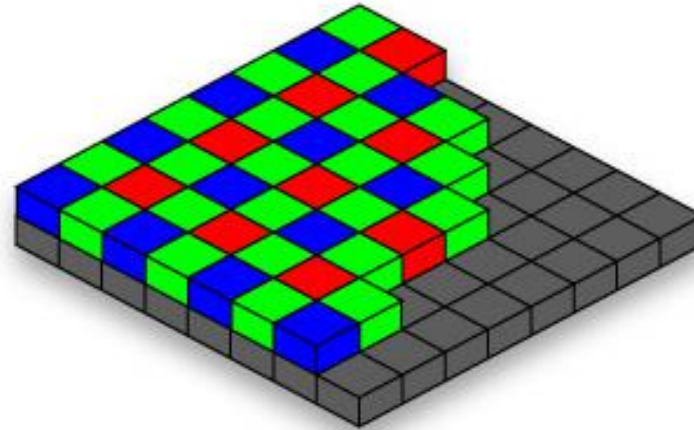


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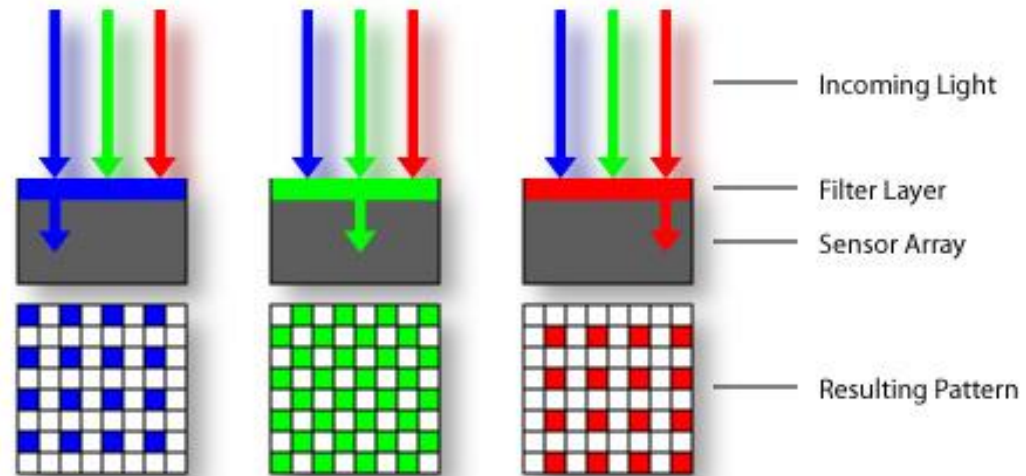
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Estimate the color



Bayer pattern



Color

■ Representation

○ for graphics & displays

- CIE chromaticity diagram
- Commission Internationale de l'éclairage-1931
- inks, displays, cameras
- X – mix of RGB
- Y – illuminance
- Z – close to blue

○ for computational analysis

- color spaces
- processing the color images

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○ Hunt-Pointer-Estevez matrix

- cone responses to XYZ mapping
- LMS: cone responses of human eye
- $Z \leftrightarrow S$
- Y – brightness
- X, Z - chromaticity

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$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 1.910\ 20 & -1.112\ 12 & 0.201\ 91 \\ 0.370\ 95 & 0.629\ 05 & 0 \\ 0 & 0 & 1.000\ 00 \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}_{\text{HPE}}$$

Color

- CIE Chromaticity diagram
 - concept of color for computations
 - brightness (white > grey)
 - chromaticity (white = grey)

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 - concept of color for computations
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 - derived parameters for chromaticity
 - x, y
 - normalized function of all tristimulus values
 - Tristimulus: a color is represented by its trichromatic coefficients X, Y, Z

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$$x = \frac{X}{X + Y + Z}$$

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$$z = \frac{Z}{X + Y + Z} = 1 - x - y$$

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$$X = \frac{Y}{y}x,$$

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○ specifies how human eye will experience light with a given spectrum

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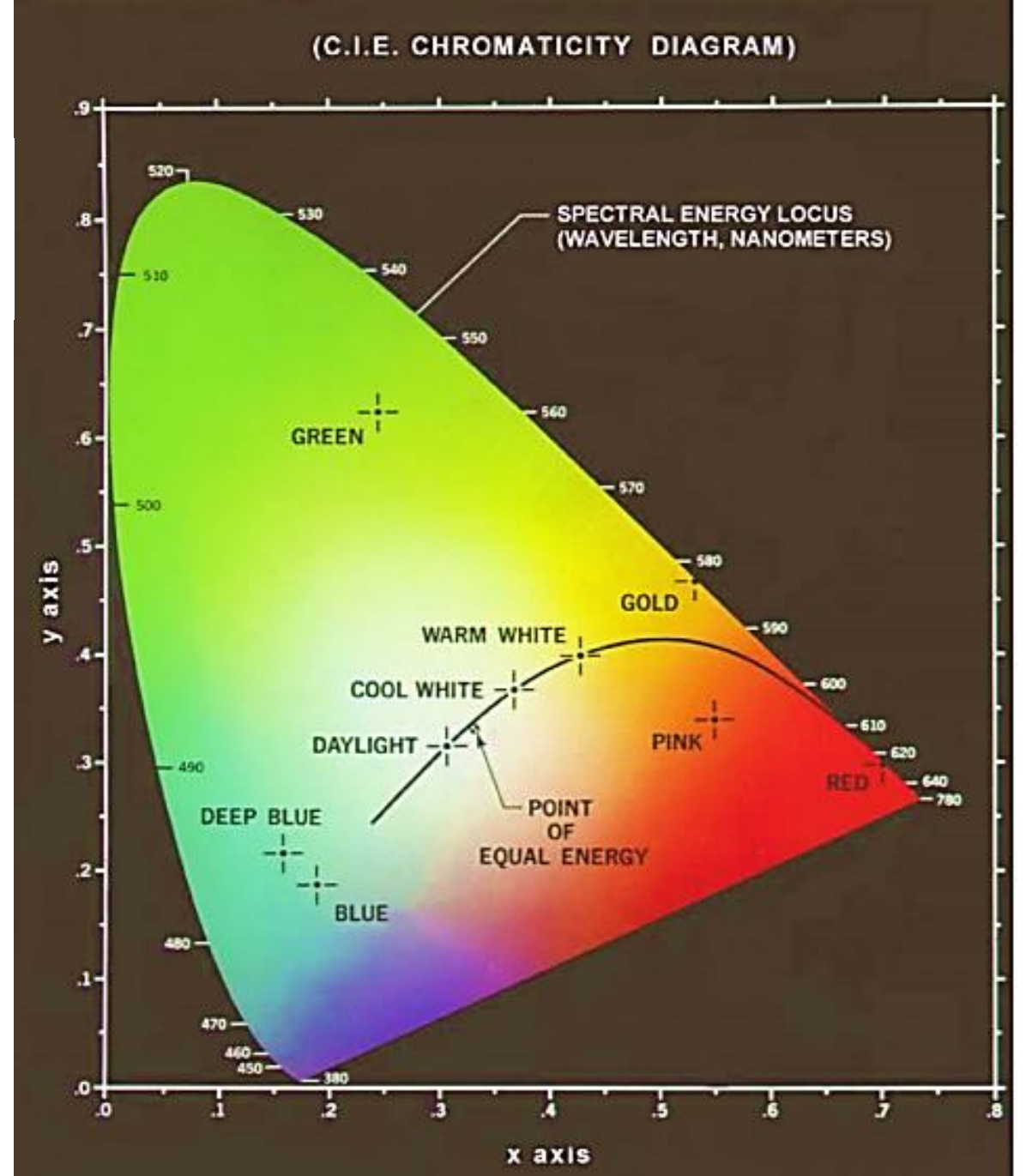
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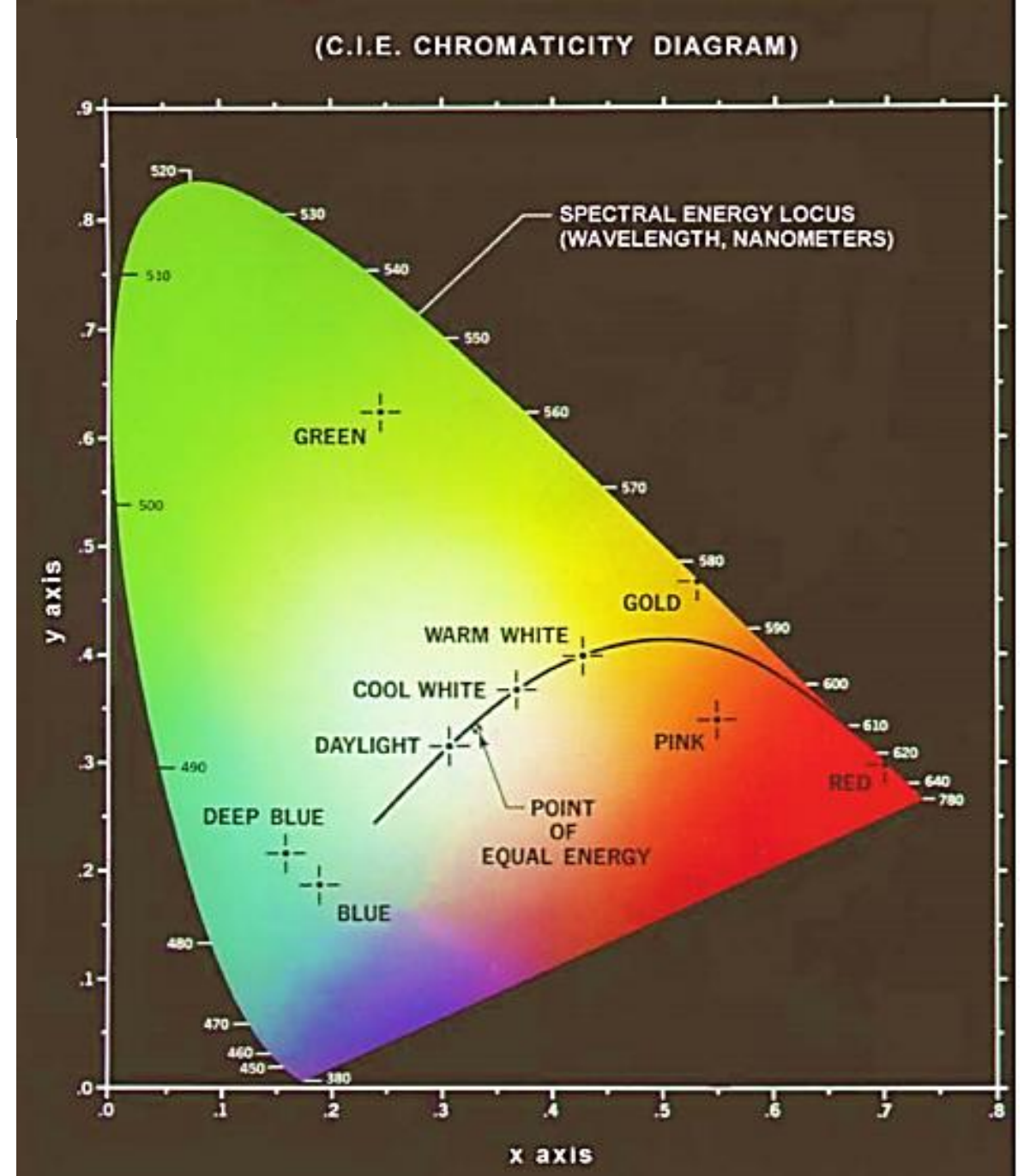
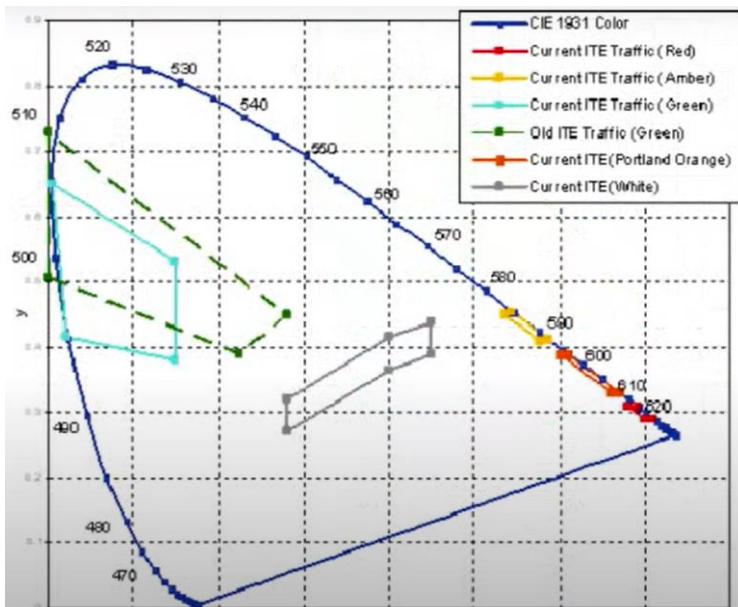
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 - all the colors that human eye can see, represented as color gamut



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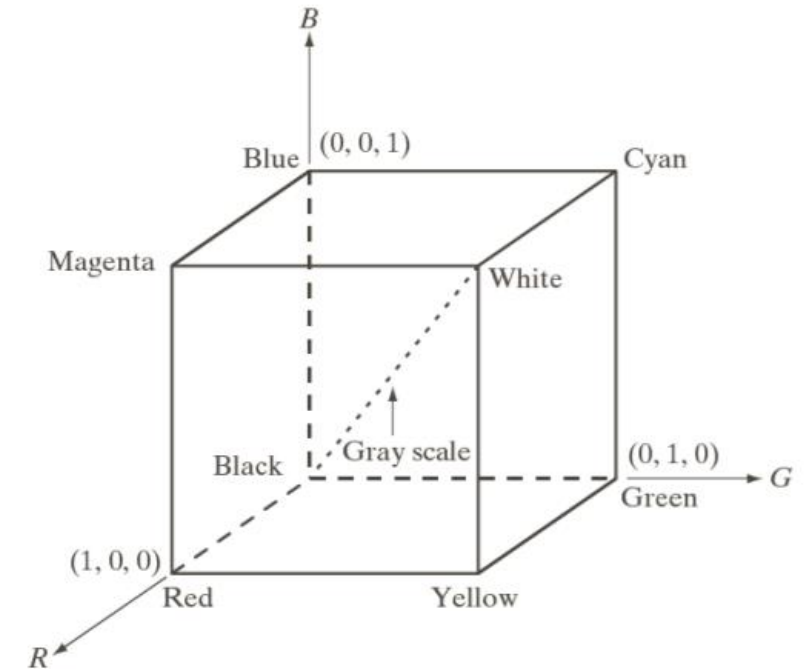
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Traffic light specifications



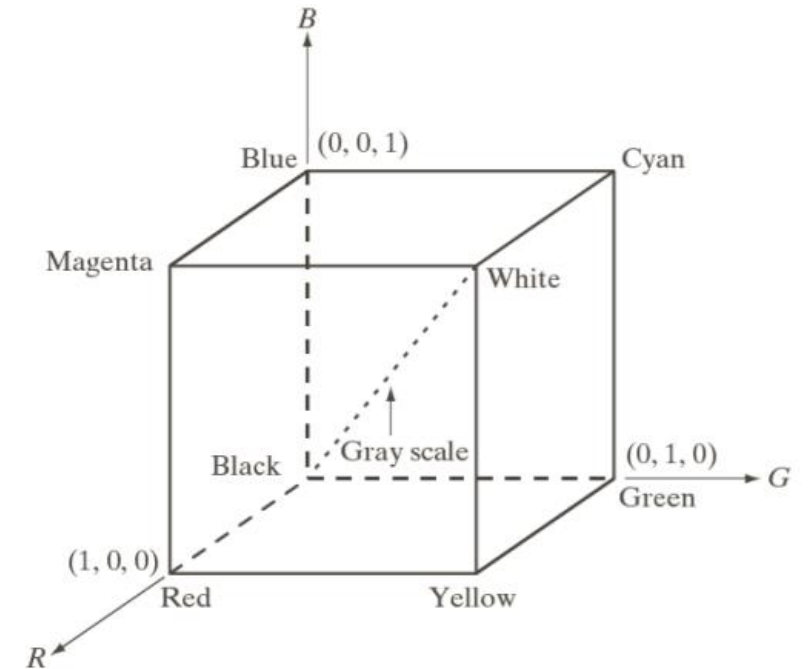
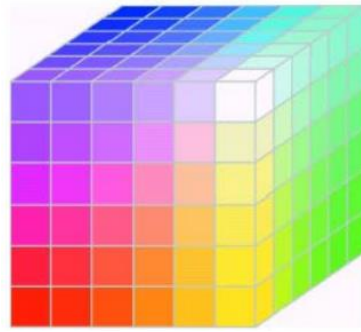
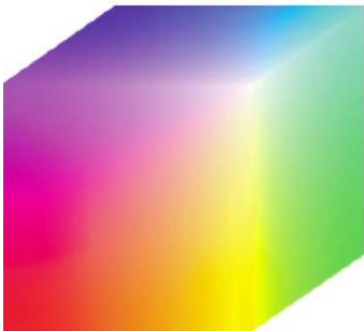
Color spaces: RGB cube

- Normalize to float values (0.0 to 1.0)
- How many possible colors in computer with 3 bytes?
- You can manipulate image inside this cube



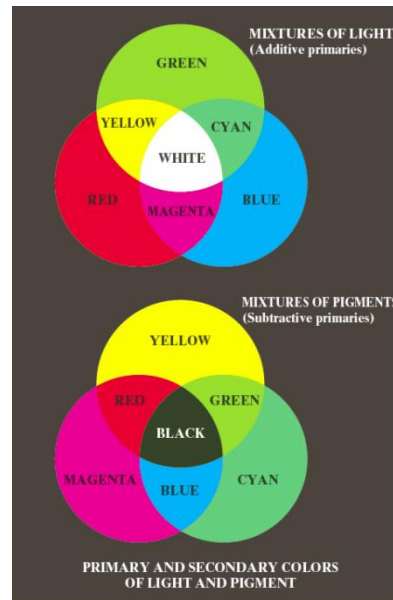
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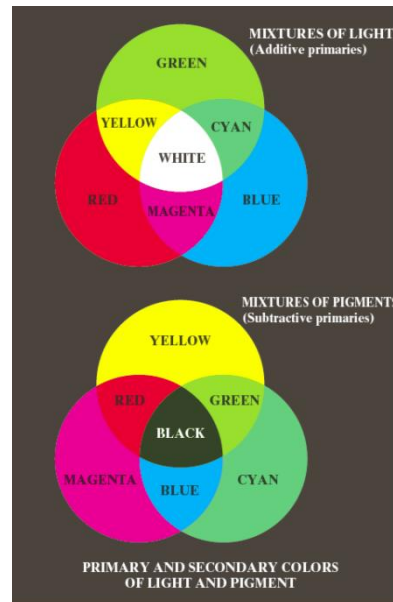
Color spaces: CMYK

- Printer vs display
- $CMY = 1 - RGB$ (vector notation)
- what is $C + M + Y = ?$
- to compensate muddy black, 'K' is added : CMYK
 $K = 1 - \max(r, g, b)$
find out other components?
- hint: $C = (1-r-K)/(1-K)$



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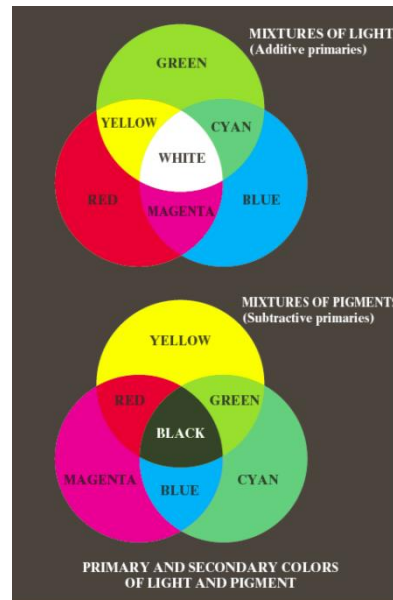


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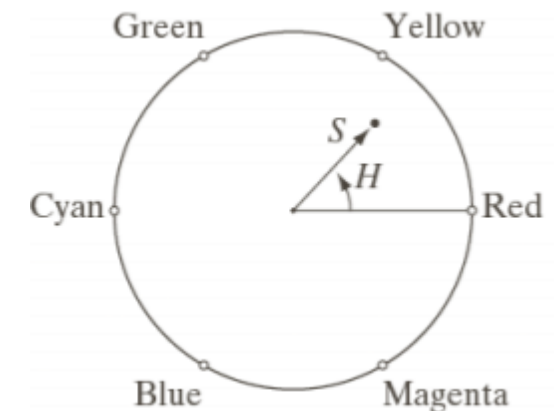


CMYK



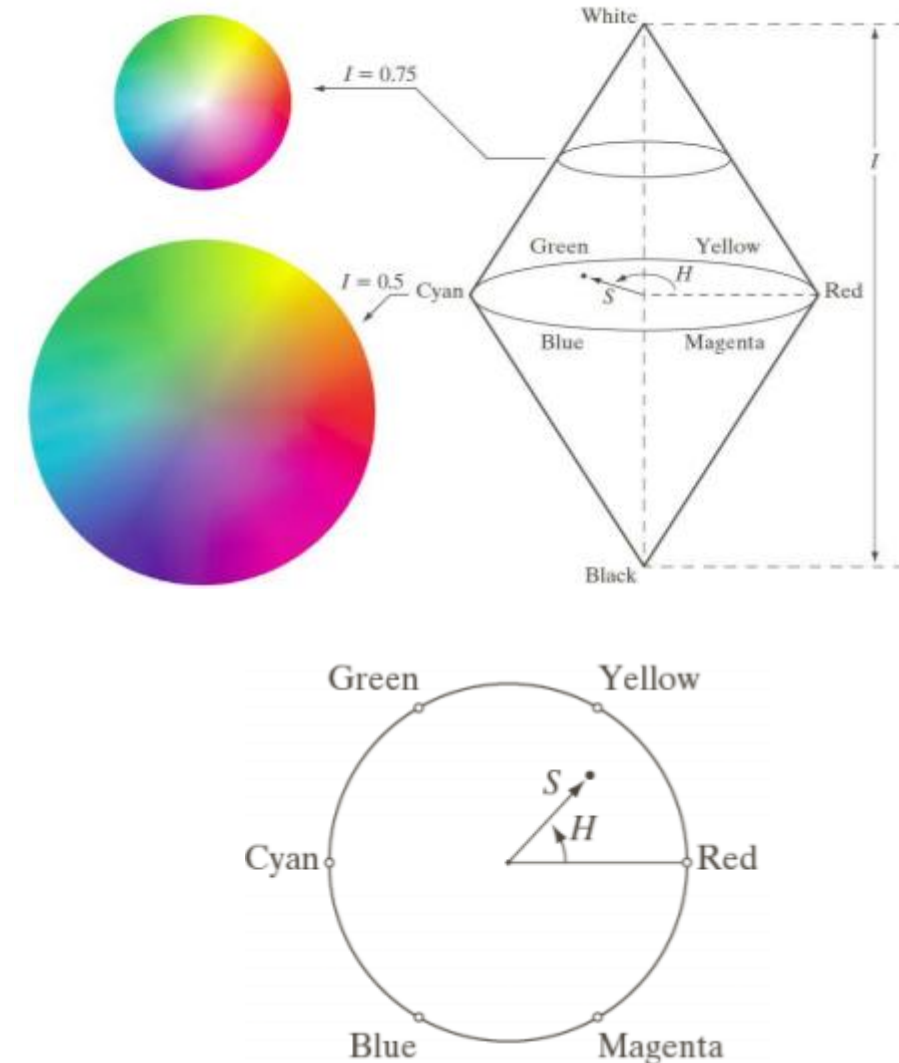
Color spaces: HSV

- Hue:
 - dominant wavelength in the mixture of light waves
 - dominant color as perceived by us
- Saturation:
 - relative purity
 - amount of white light mixed in hue to get a color
- Value:
 - also called brightness
 - achromatic notion of intensity



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Travelling inter-spaces

- It's nothing but converting image from one space to another

$$I = \frac{1}{3}(R + G + B)$$

$$S = 1 - \frac{3}{R+G+B} \min(R, G, B)$$

$$H = \begin{cases} \theta & B \leq G \\ 360 - \theta & B > G \end{cases}$$

where

$$\cos \theta = \frac{\frac{1}{2}[(R - G) + (R - B)]}{[(R - G)^2 + (R - B)(G - B)]^{1/2}}$$

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<https://www.rapidtables.com/convert/color/rgb-to-hsv.html>

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RGB to HSV color conversion

Enter 6 digits hex code or enter red, green and blue color levels (0..255) and press the *Convert* button:

Enter RGB hex code (#):	<input type="text" value="FFFF00"/>
or	
Enter red color (R):	<input type="text" value="255"/>
Enter green color (G):	<input type="text" value="255"/>
Enter blue color (B):	<input type="text" value="0"/>
<input type="button" value="Convert"/> <input type="button" value="Reset"/>	
Hue (H):	<input type="text" value="60"/> °
Saturation (S):	<input type="text" value="100.0"/> %
Value (V):	<input type="text" value="100.0"/> %
Color preview:	

Color correction

- Acquired image might be in different illumination or in shadow

$$\begin{bmatrix} \tilde{r} \\ \tilde{g} \\ \tilde{b} \end{bmatrix} = \begin{bmatrix} \alpha_r & 0 & 0 \\ 0 & \alpha_g & 0 \\ 0 & 0 & \alpha_b \end{bmatrix} \begin{bmatrix} r \\ g \\ b \end{bmatrix}$$

Color correction

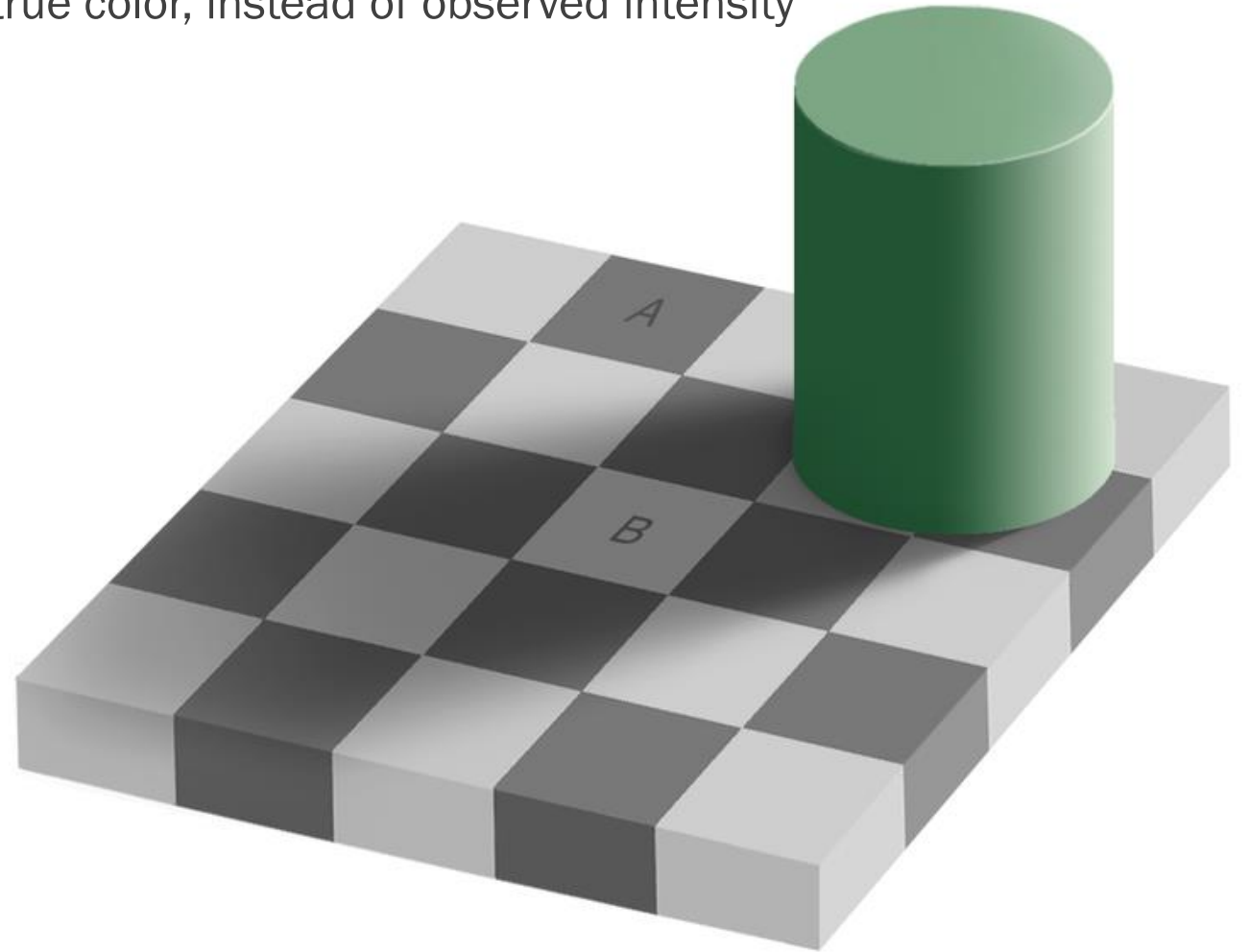
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- White world assumption: brightest pixel should be white
 - divide by max value
- Gray world assumption: average value should look like grey
 - $m = \text{avg over image}[(r+g+b)/3]$
 - $\tilde{r} = r * \text{avg}(r)/m$
- Histogram equalization on color channels

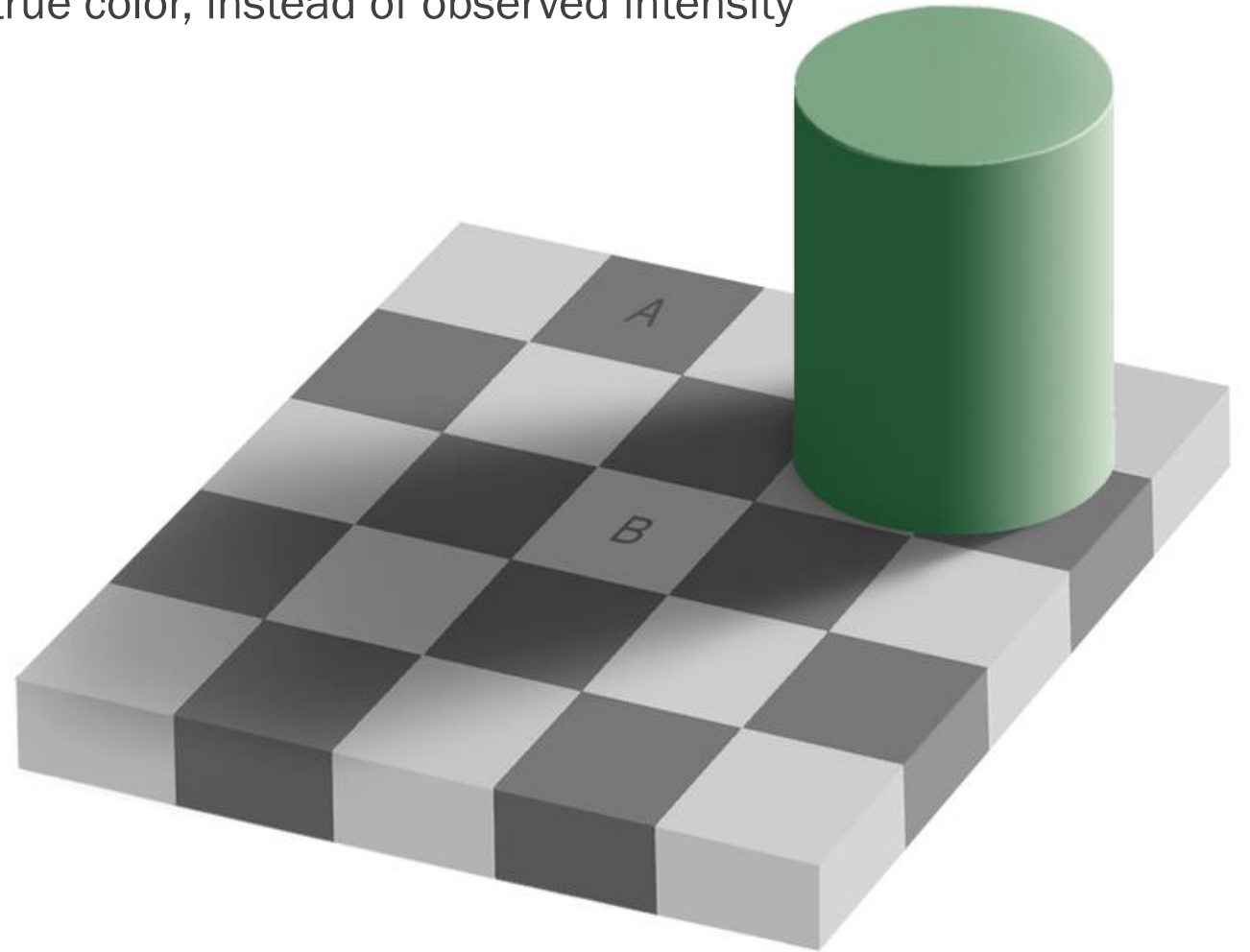
Color constancy

- Interpret object surface in terms of albedo or true color, instead of observed intensity
- Contextual phenomenon
- e.g. banana appears yellow even in blue light



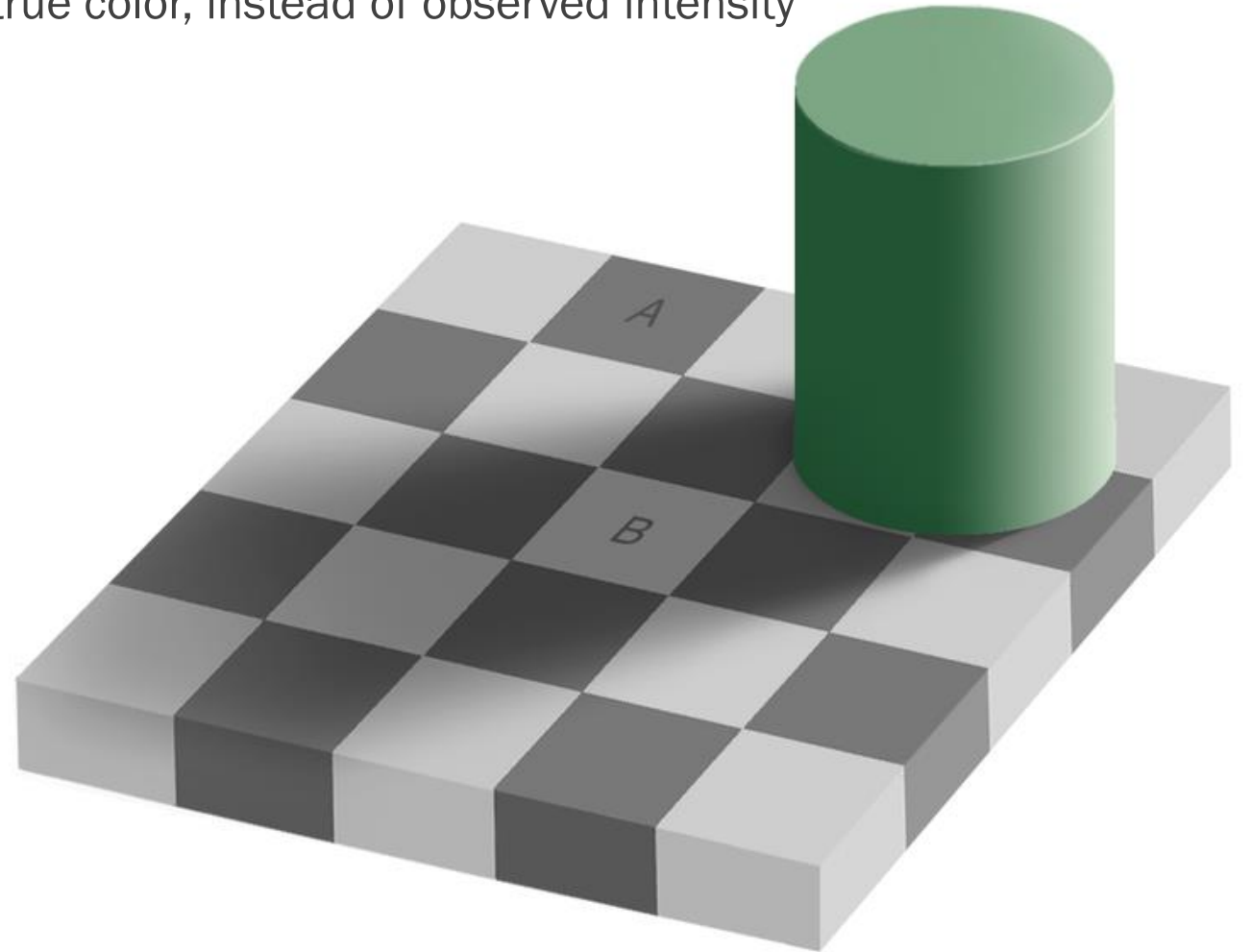
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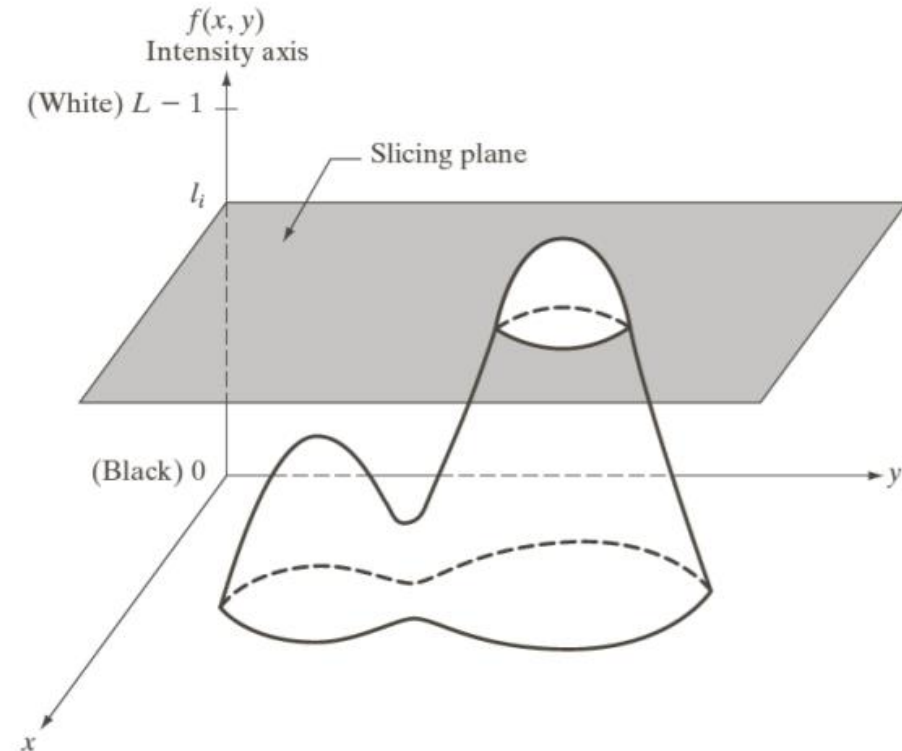
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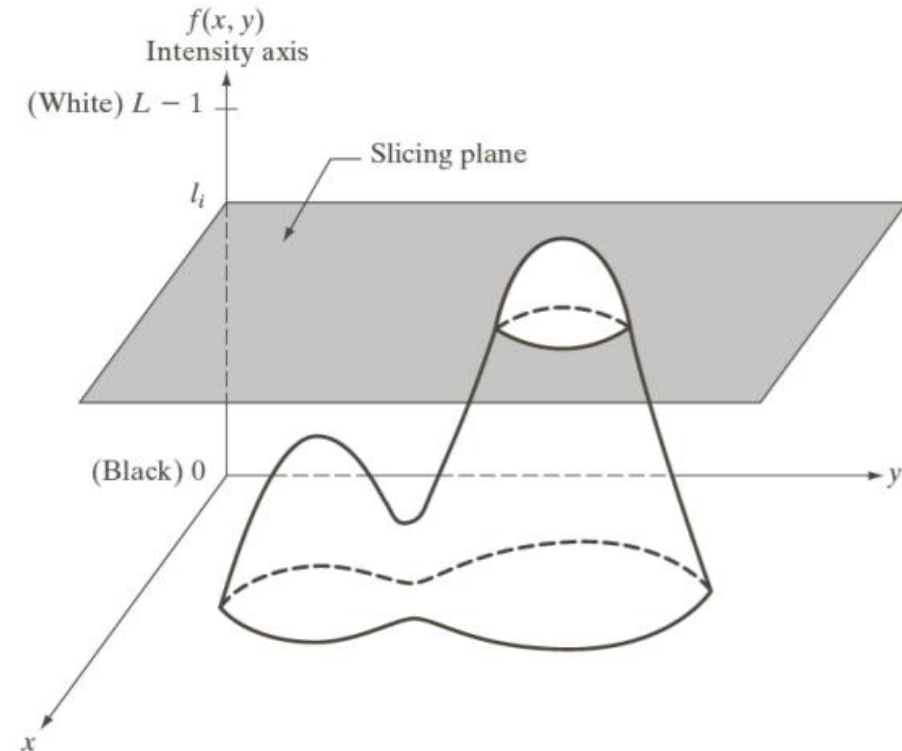
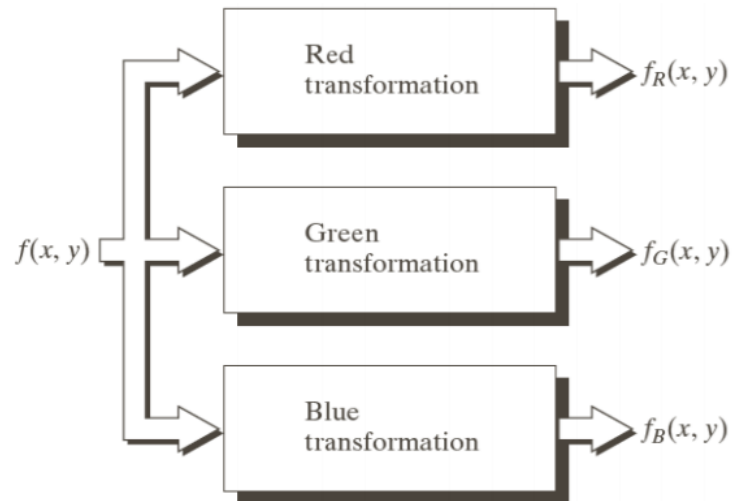
Pseudocolor image processing

- assign colors to grey values (e.g. via intensity slicing)
- Note: different from image colorization
(estimate underlying true color for a given grey image)



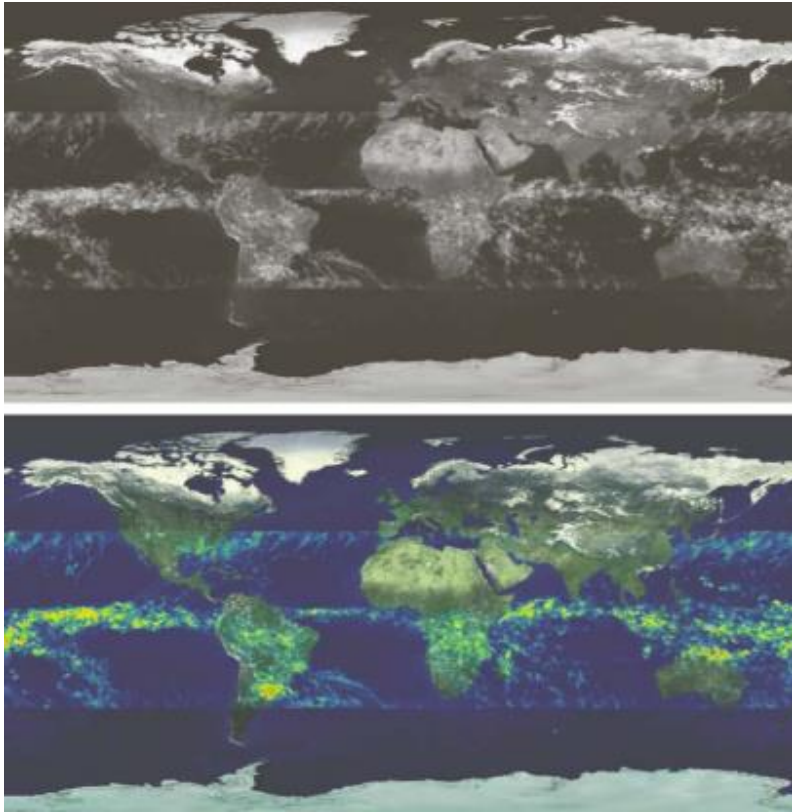
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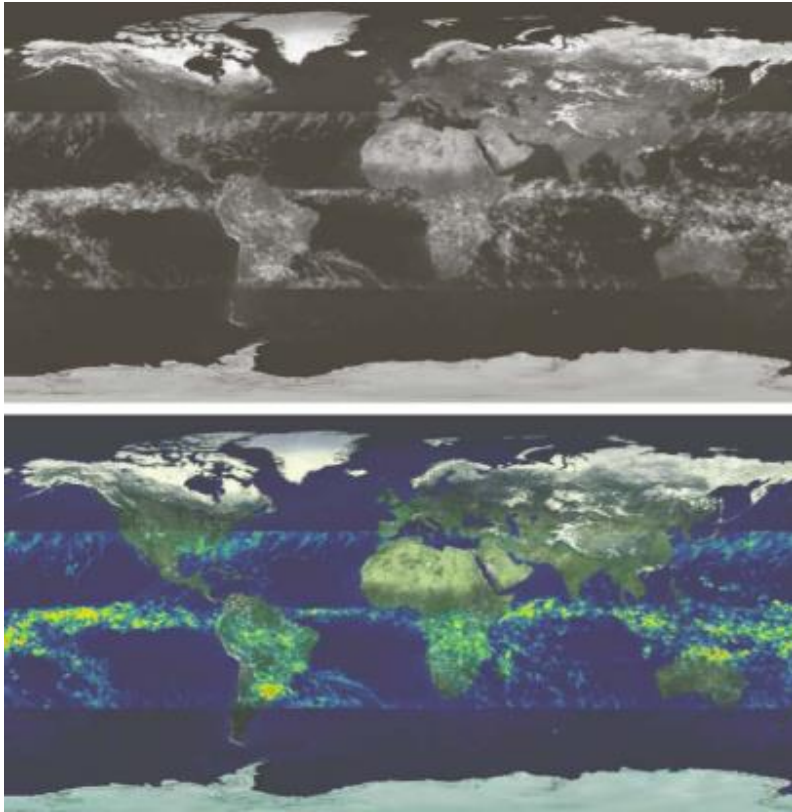
Pseudocolor image processing

satellite

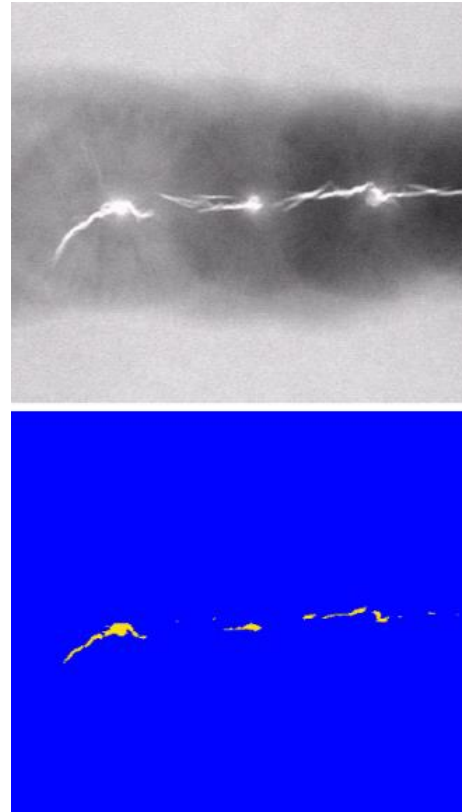


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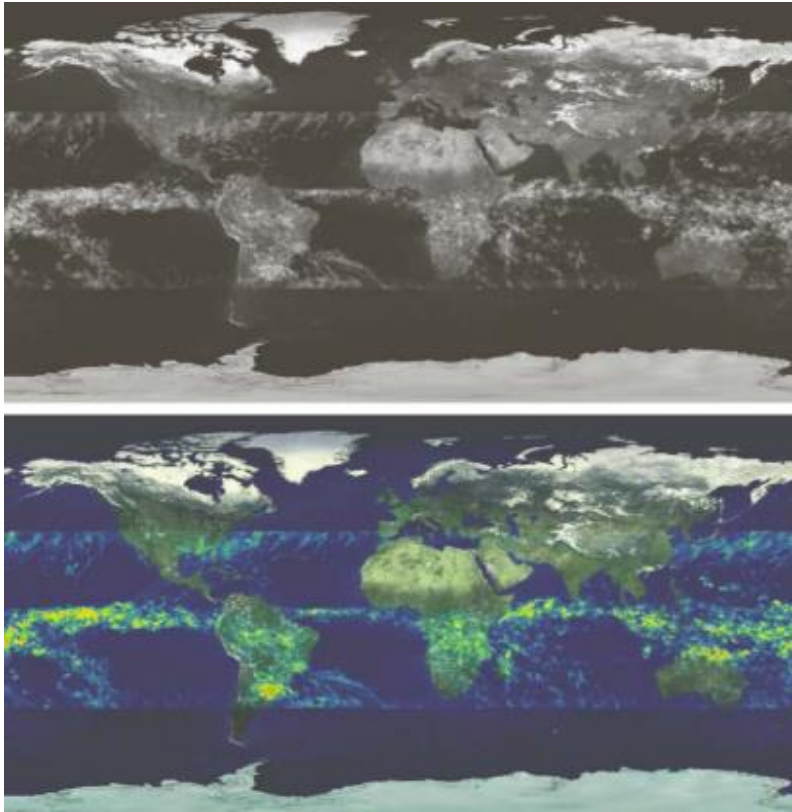


X-ray

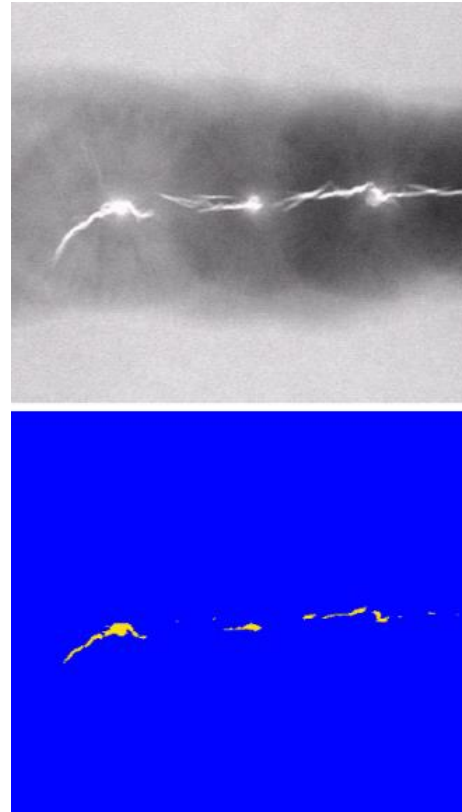


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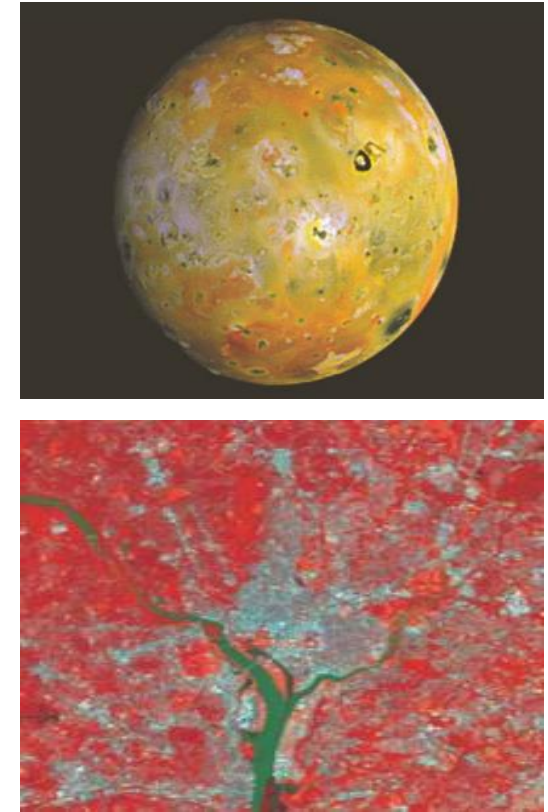
satellite



X-ray



Multi-sensors



Credit: U. Berkeley & NASA

Pseudocolor image processing

- Transformation functions

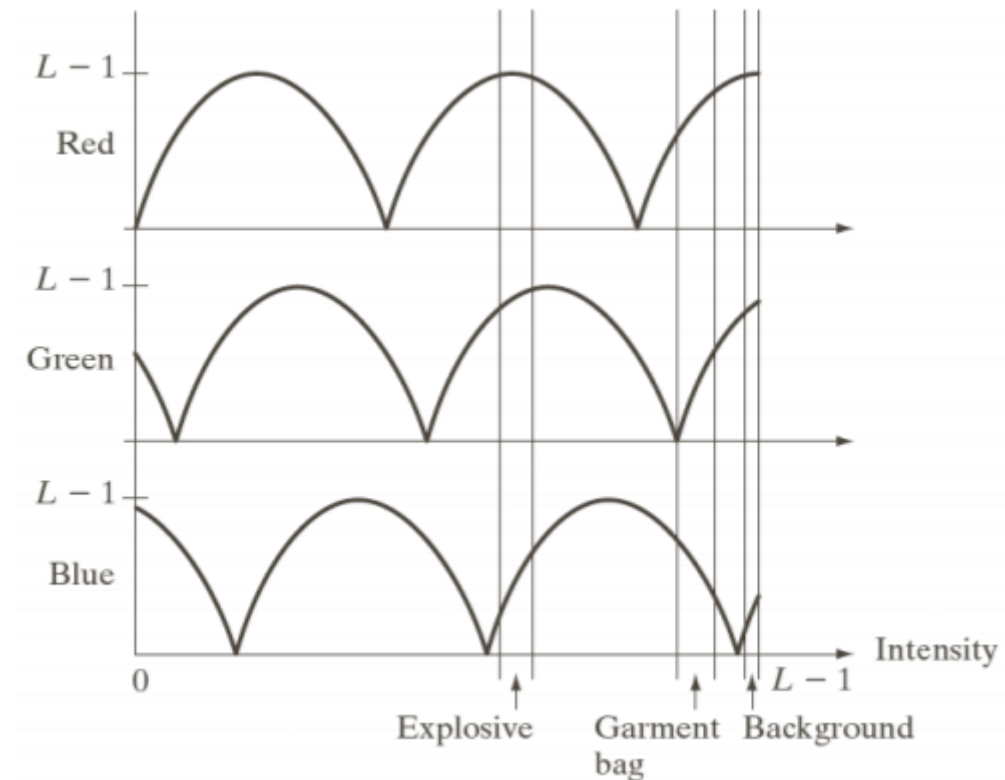
Input X-ray image



Pseudocolor image processing

- Transformation functions

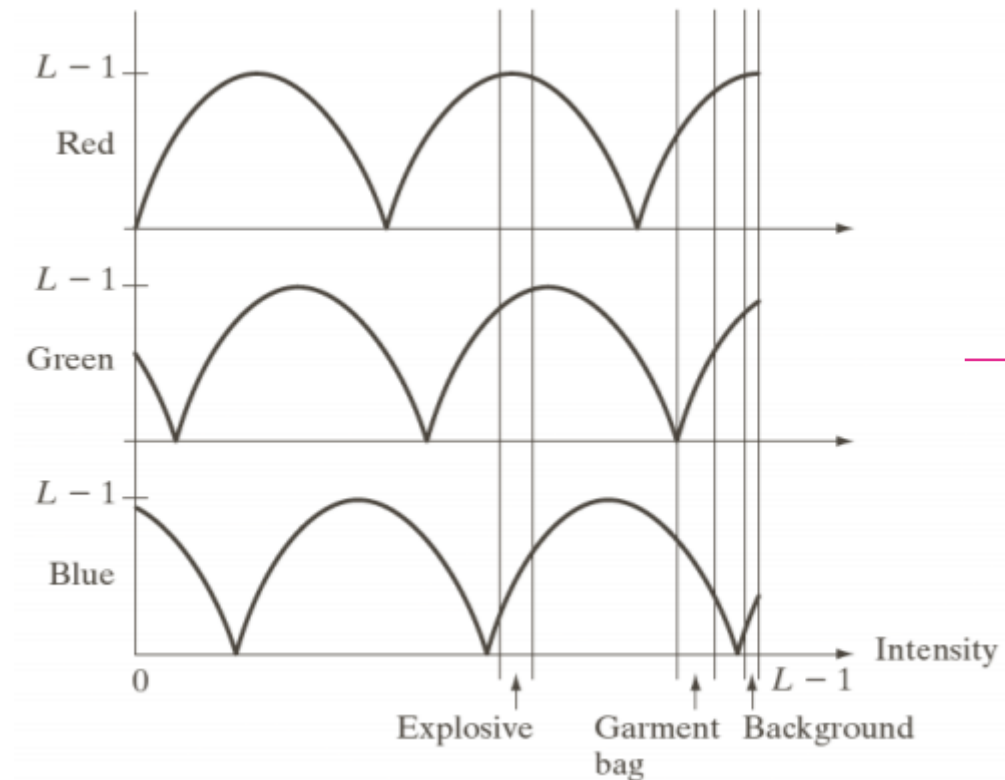
Input X-ray image



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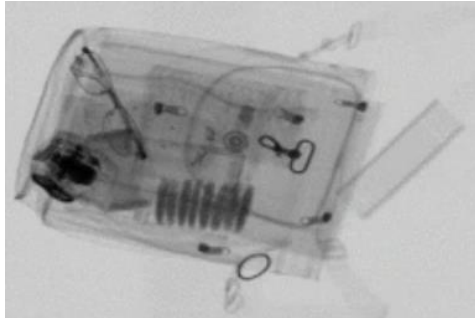
Input X-ray image



Output?

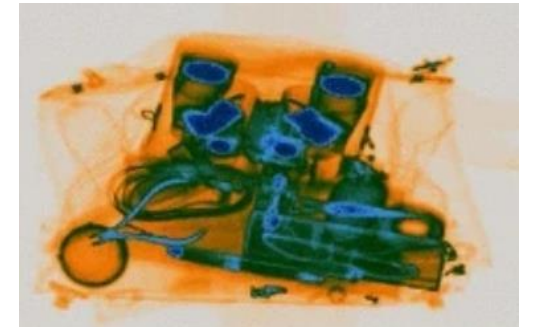
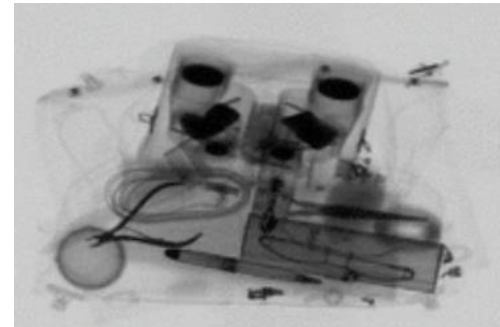
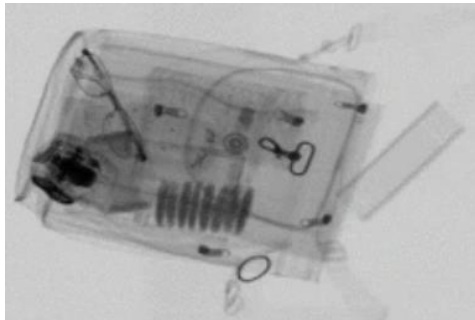
Pseudocolor image processing

- Transformation functions
 - with different transformation functions



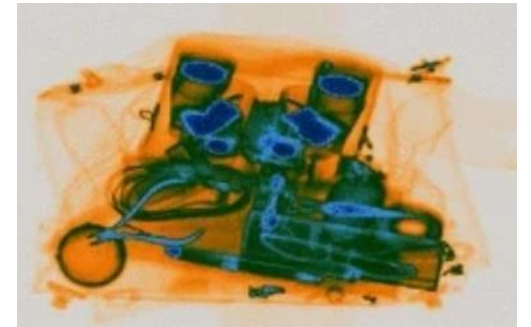
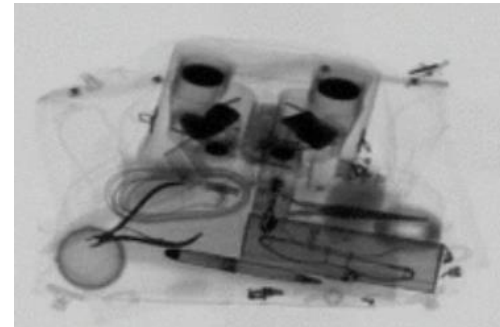
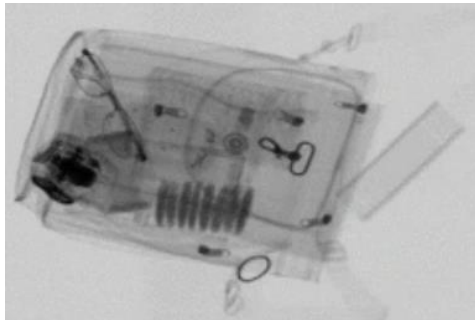
Pseudocolor image processing

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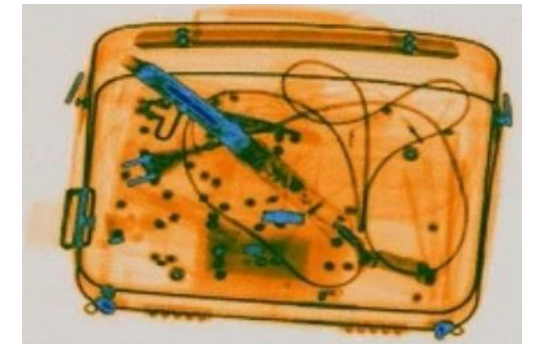
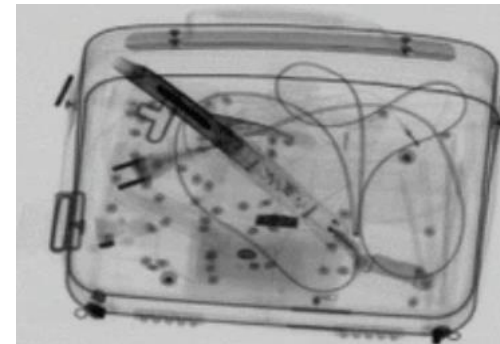
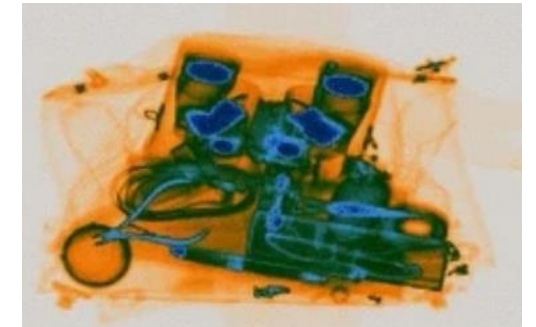
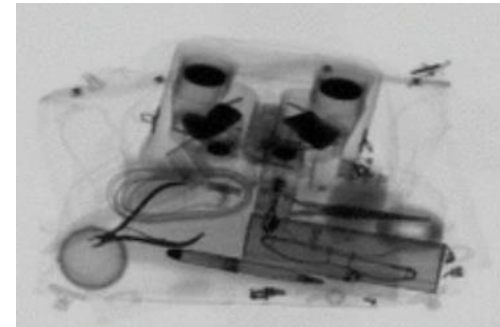
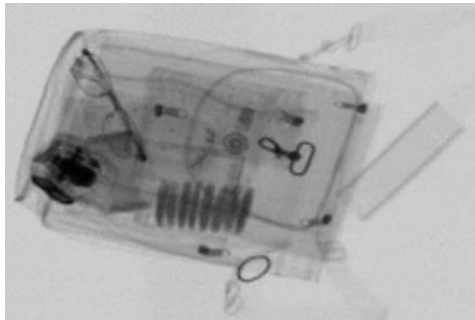
Pseudocolor image processing

- Transformation functions
 - with different transformation functions



Pseudocolor image processing

- Transformation functions
 - with different transformation functions



Conclusion

- Color fundamentals
- Color spaces

Conclusion

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- Color spaces

□ Light sources

- Spectra to retina sensing

□ Color

- Cones
- Color spaces
- Pseudocolor images

Conclusion

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"Blurring the pseudocolors in friendships, reduces the relational spaces & life becomes Colorful."

-TS

